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A GEOLOGICAL RECONNAISSANCE OF THE COAST OF ANATOLIA.(U)

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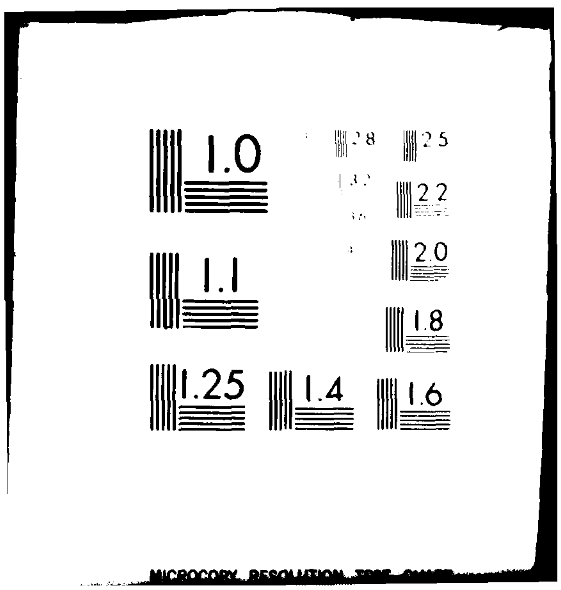

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Director
Geography Programs
Earth Sciences Division
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217

Dear Dr. Bailey:

I herein submit a final-interim report on my contract research "A Geological Reconnaissance of the Coast of Anatolia". The contract numbers are noted to the above right. This project has undergone a number of difficulties, not the least of which was the fact that I underwent a long and serious illness during the time of the contract. Accordingly, the contract period was extended to December 31, 1979. At this time, all of the work on the contract is still not completed. Turkey has been in a turmoil during these years and my colleagues, upon whom successful completion of the research has depended, have been undergoing severe difficulties in terms of their working conditions. These have included extreme disruptions of schedules caused by shutdowns of their University (actual shooting confrontations between student groups), and frequent changes of federal administration and administration of associated agencies. Accordingly, it has been exceedingly difficult to complete the contract as originally envisaged. Nevertheless, a great deal of progress has been made including some peripherally related manuscripts that are now undergoing review for publication.

I use the word final-interim report above as work still continues on this project. It was and is my intent to complete the project as planned. No further call will be made upon the Office of Naval Research in terms of funding for this. Nevertheless, my colleagues in Turkey and myself are continuing to work on a technical report on the subject of the grant. We believe that this will be a major advance in our understanding of unique shoreline types, the original reason for doing a reconnaissance of the coast of Anatolia. In view of the above, I submit this report to in a sense close out the contract but with the understanding that you will hear from us in the future via a major published technical report either in the form of an in house technical report or a published professional journal article.

I regret the above circumstances but feel that the only detriment to the project of the whole has been one of time rather

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than quality and completion of the result. I trust that this is satisfactory to you.

Yours very truly,

John C. Kraft
Chairperson and Professor

JCK/lc

cc: Dr. Dennis Conlin
Mr. Thomas E. White, Director, Contracts & Grants
Office of Naval Research Resident Representative, Univ. of Pennsylvania, David Rittenhouse Laboratory

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A GEOLOGICAL RECONNAISSANCE OF THE COAST OF ANATOLIA
(Report as per contract date Dec. 31, 1979)

Kraft, John C., Dept. of Geology, Univ. of Delaware, Newark, Delaware, 19711

Introduction

The Anatolian subcontinent between the Black Sea, the Aegean Sea, and the Mediterranean Sea, is comprised of shorelines of ancient blocks of highly variable geology, mostly cliff-like (some cliffs undergoing rapid erosion, and some very slow erosion in terms of long term geologic time) with the cliff coast areas interspersed with depositional areas. Much has been written about the geology of the coasts of the Anatolian massif. However, the majority of the geologists that have treated this subject have dealt with the rocks of the long term geologic record. Most geologists have concerned themselves with studies of the ancient rocks (those not undergoing active change in the short term, less than 100 year period time frame). The majority of the studies appear to be tectonically oriented ~~(Figure 1)~~. The Anatolian massif is but one of a major group of highly mountainous tectonic blocks that have undergone formation over the Tertiary Period of geologic time (past 50-60 million years) in the Mediterranean area.

Only a few geologists have paid attention to the evolution of shoreline morphology. Most coastal studies are not process oriented, although the past several years indicate rapid advances in this area by Turkish geologists and geomorphologists. Based on numerous conferences and individual discussions with geologists of the Mediterranean region, in Turkey, Greece, Italy, France, etc., there is a tendency to regard the sediments of the recent past (past 100 to 10,000 years) as nc being worthy of study. Important exceptions occur. For instance, with the formation of the Department of Oceanography at Ege University at Bornova, in Izmir, there is an indication of intent to dramatically increase the study of the nearshore and deeper marine areas surrounding Anatolia. Further, a number of geomorphologists have studied various locations around the Anatolian massif and Turkish Thrace from the point of view of classical geomorphic evolution. A few of these reports deal intensively with process oriented studies. Examination of maps shows that depositional changes from the past several thousand years and more particularly from the past 100 or less years are important locally and that processes in action have led to critical changes in morphology of the shorezone area.

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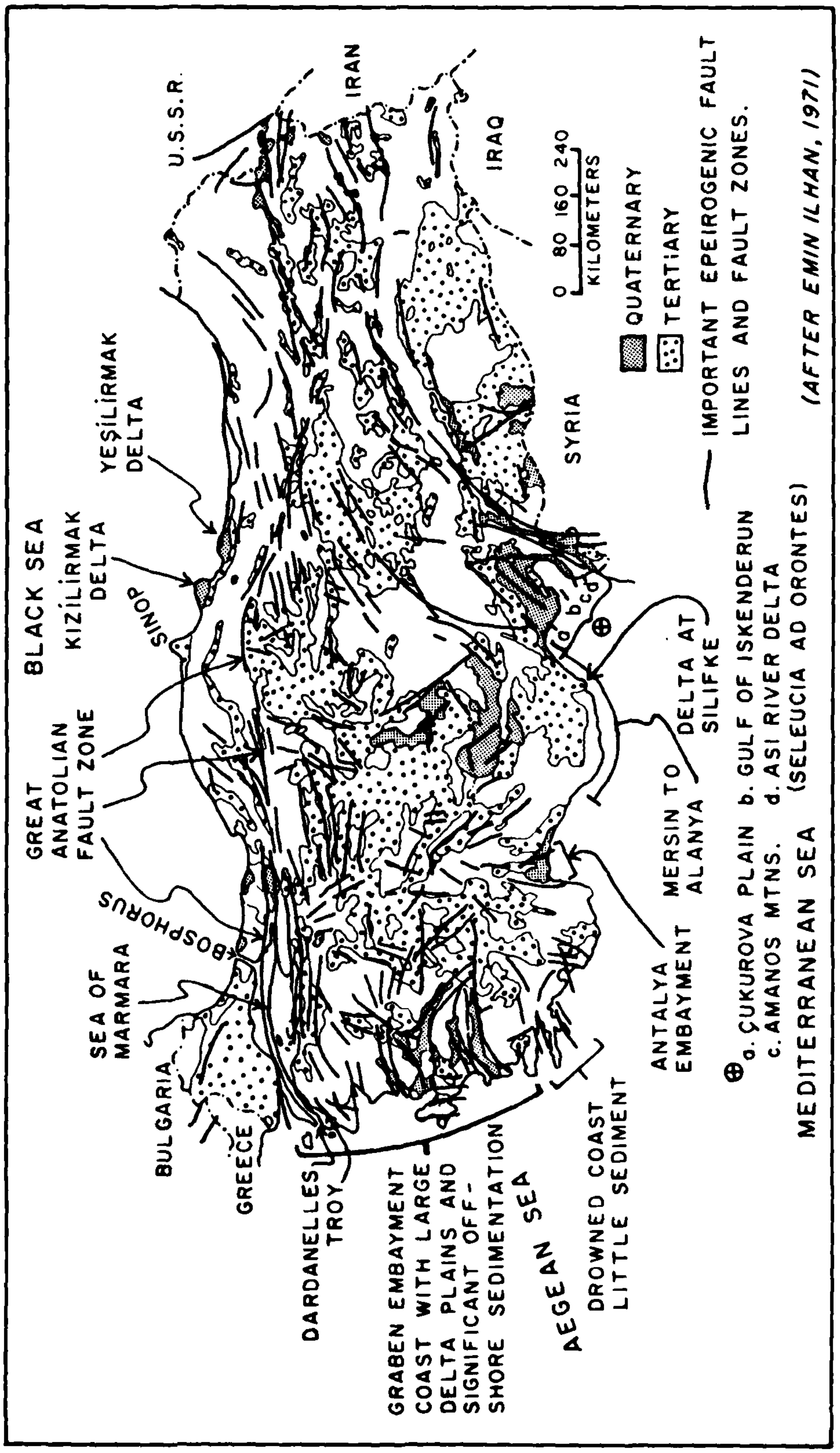

Figure 1. An analysis of the coastal elements of Anatolia related to the tectonic structural elements and Tertiary and Quaternary Period block units of the Anatolian massif (after E. Ilhan, 1971).

Coasts of Anatolia

The physiography of the shoreline of Anatolia is almost totally controlled by tectonics. The Anatolian massif is part of a plate of the Earth's crust that is in collision with a number of other small blocks of the Earth's crust (Figure 2). The general tectonic trend of faulting in Anatolia is east-west. However, important secondary trends tend north-south and are particularly important in shoreline physiography in the southeast of Turkey and in the west central and northern shoreline of the Aegean Sea (Figure 1). The Great Anatolian fault runs in an east-west direction through the northern part of Anatolia from the border of the U.S.S.R. and Iran westward through the Sea of Marmara and thence into the Saros Gulf just east of the Turkish border with Greece. The geology of Turkey is extremely complex. Coastal zones, as should be expected, are closely related to the tectonic or fault trends. The northern shoreline, along the Black Sea, is predominantly formed by coast parallel faults which sometimes merge on shore and sometimes are in the nearshore-offshore shelf. The shorelines along the Aegean coast are dominated by horst and graben structures in an east-west axis with a secondary line of faulting in a north-south direction along the border of the Aegean Sea. The southern coast of Anatolia includes two major tectonic embayments, the Antalya embayment with a north-south trend and the embayment at Iskenderun-Çukurova in the southeast, with a northeasterly tectonic trend. Turkey is extremely active seismically. Neogene to present sedimentation and/or tectonics are predominant in the evolution of the various types of shorelines.

Emphasis in this reconnaissance geology includes a number of geological-geomorphological variants. One, in the northeastern corner of the Mediterranean is the Çukurova plain and the Gulf of Iskenderun. The Çukurova plain is a floodplain-delta plain, formed of Holocene Epoch sediments deposited by the Kulek River which flows by Tarsus across the western plain, The Seyhan River which meanders across the central plain and exits in its present delta toward the west, and the Çeyhan River which meanders across the plain, around a small mountain range (Misis Mtns.) and exits to the east and southeast into the Gulf of Iskenderun. This major tectonic embayment, which includes the delta plain of the Çukurova and the Gulf of Iskenderun, is controlled by northeast-southwest fault zones. To the northwest of the Cukurova plain lies the very high Tarsus mountain range. Extending southwesterly along the faulted base of the Tarsus Mountains-Çukurova plain one merges with the Mediterranean Sea in a straight line continuation from the city of Mersin westward to Silifke. Preliminary observations suggest that the northern mountain range in Cyprus, which extends to the northeast at Cape Ayandria on Cyprus, is continued by a

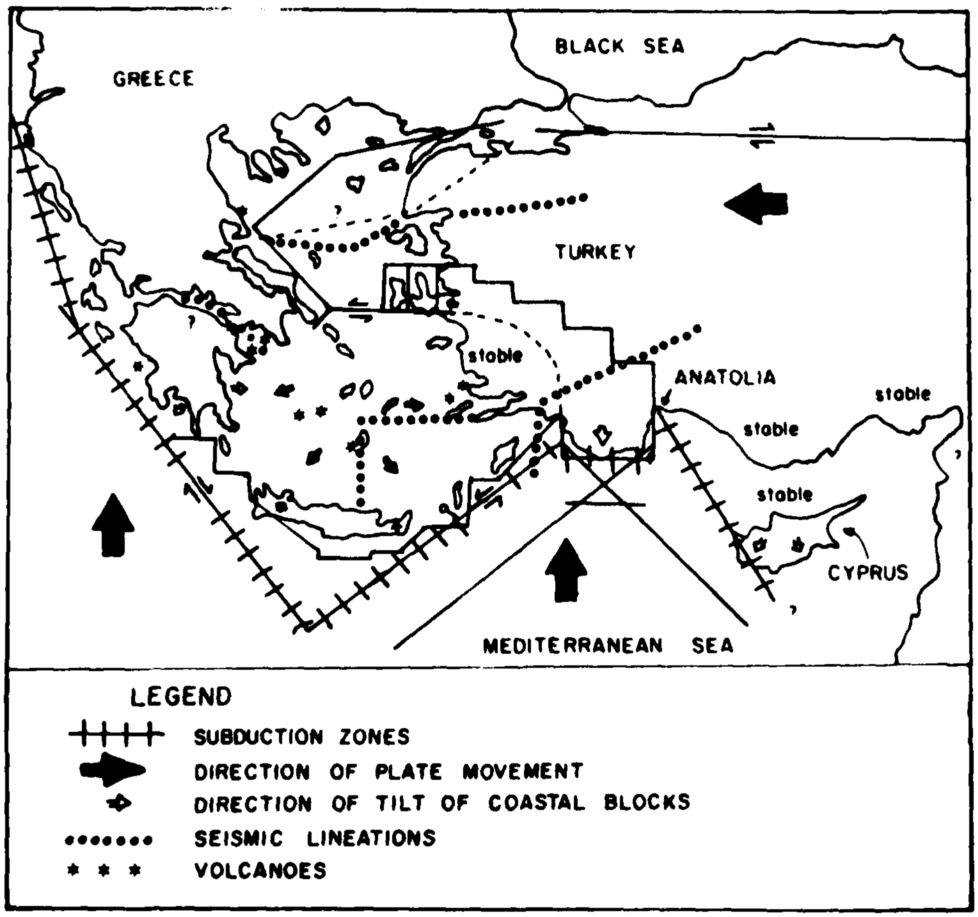

Figure 2. A plate tectonic analysis of the Aegean Sea and adjacent regions showing the lines of collision of major blocks of the earth's crust and their relationship to Anatolia (Flemming, 1978).

physiographic scarp under the sea into the Çukurova plain and emerges as the Misis Mountains on the northwestern flank of the Iskenderun Gulf. The shelf to 200 meters depth in the Iskenderun Gulf and to the southwest of the Çukurova plain is approximately 20 km wide and suggests that this embayment has been receiving sediments at varying sea levels during the entire Quaternary Period.

The shoreline from the southwestern extension of the fault boundary between the Taurus Mountains and the Çukurova plain extends from Mersin westward to Erdemli. From this town westward to Alanya, Paleozoic, Mesozoic, and metamorphic complexes form a high mountain range (Paseli) which drops off sharply to the sea. The nearshore shelf to -200 meters is very narrow and almost in contact with the coastline at Alanya. High mountains with sharp cliffs drop off to the sea with a very narrow shelf. From Alanya westward to Antalya the shoreline is a long sandy strandline. The plain becomes gradually wider as one goes westward towards Antalya. A major tectonic embayment controlled by a north-south fault to the west of Antalya between the Bey Mountains and Akdag defines the western side of the Antalya embayment. The northern and eastern flank, of the Antalya embayment is in part tectonically controlled. The Antalya embayment includes a partial broad shallow shelf east of Antalya towards Alanya. However, at Antalya, this major city is located on a high cliff incised into travertine sediments. Travertine fans of the Antalya region are high and widespread and extend over 20 km inland to the north. The travertine fans rise high above the coastal plain in a number of steps.

From the peninsula at Bodrum and the island of Kos (Greece), the western shoreline of Anatolia (Aegean Sea) extends northward to Edremit at the east of a major embayment north of the island of Lesvos (Greece). This shoreline is one of eastwest trending faults forming major horsts and grabens. In some cases the grabens are infilled to the limits of the east-west trending mountain ranges. Examples of this are the delta of the Büyük Menderes River which has extended its delta westward over 20 km since Roman time, circa 2,000 years ago. This is an area in which major cities of the past such as Miletus, Priene, and Heracleia have been abandoned by the sea by sediment bypass with delta progradation. A similar situation exists on the Küçük Menderes (Cayster) River just to the north of the Büyük Menderes valley. The Küçük Menderes River is famous for being the river which formed a delta which bypassed the important ancient city and capital of the province of Asia, Ephesus (Efes). Linear mountain ranges trending east-west protrude into the Aegean Sea. The embayments between them are being infilled by sediment.

At Izmir, a deep water embayment still exists along the southern flank to provide a deep and very important harbor. To the north of this embayment, the Gediz River is forming a large delta which is tending to infill the Izmir Gulf. However, here, as in the Büyük Menderes and elsewhere, large amounts of water are being removed from the river bed for irrigation purposes and the delta progradation process is somewhat diminished, although still active. The 200 meter contour lies further offshore to the west in this region and surrounds many of the offshore Greek islands. This is indicative of delta progradation over the many Quaternary Period stadials and interstadials (rise and fall of sea level) of the past 1.5 million years. The shallow broad shelf was probably infilled by alluvium from the many rivers flowing to the west along the graben valleys of western Anatolia. The process appears to have been initiated in late Neogene time or at the beginning of the Quaternary Period.

The coast of the Biga peninsula has been studied in some detail. The southern shore of this high rocky peninsula is bounded along the south by a fault scarp forming the Edremit Gulf. Along the western side of the Biga peninsula, the Tuzla River forms a small delta in the southwest of the peninsula. Further north, the offshore island of Bozcaada is an obvious erosional remnant of a time when the Biga peninsula extended further seaward. In the northwest corner of the Biga peninsula, Neogene sands, limestones, silts and conglomerates are being actively eroded and the cliff coast is retreating at a rate of approximately one meter per year. The northern part of the Biga peninsula is bounded by the Dardanelles. The Sea of Marmara lies astride the great Anatolian fault. It is a deep depression, with depths to 1,380 meters below sea level. The greater Anatolian fault trends through the Sea of Marmara, inland and then exits in the Saros Gulf to the north of Gallipoli (Geliblou peninsula). Shorelines along the straits of the Dardanelles are comprised of precipitous cliffs with small, minor deltas protruding northward, such as that at the city of Çanakkale.

An intensive study of the geology and evolution of the plain of the Kara Menderes River (ancient Scamander River) along the southwestern side of the Dardanelles was undertaken. This study included several weeks of field work including the drilling of seven test holes along the axis of the Kara Menderes. The reasons for studying this area were two-fold. One, it did not appear that the Kara Menderes valley occupied a graben or fault controlled embayment. Rather, it crossed and is incised through a series of gently southerly dipping cuestas comprised of Neogene sediments. At the southern end of the valley, approximately 17 km from the Dardanelles, the valley has a sharp border at the Araplar gorge where it emerges from a deeply incised meander valley in the higher plateau of the Biga peninsula. Two, as anticipated from

other research in Greece, it was discovered that the river plain of the Kara Menderes underwent a major marine transgression over 15 km southward with the rapidly rising sea levels of approximately 6,000 to 7,000 years before present. Since that time, river flood-plain aggradation and delta progradation have moved the shoreline to the north where the present delta protrudes into the deep channel of the Dardanelles (Figure 3). The delta has probably reached its maximum northward protrusion as the currents in the Dardanelles are very strong, flowing from the Sea of Marmara into the Aegean Sea, with minor nearshore edies or reversals.

Another shoreline section studied was that of the Black Sea from Sinop on a prominant peninsula into the Black Sea and southeasterly along the deltas of the Kizilirmak and Yesilirmak deltas. This section of the Black Sea shoreline is strongly controlled by a fault system parallel to the coastline and sometimes precisely at the coastline. It is a shoreline area of very high mountain ranges comprised of Mesozoic and Tertiary rocks. The peninsula at Sinop is an erosional rocky remnant protruding north of the main coastal fault line of the Anatolian massif. Shorelines to the southeast of Sinop are gravel beaches with frequent areas in which high mountain ranges plunge by sharp cliffs into the sea. From Alacam westward to Gerze the shoreline is one of extremely high mountains dropping off precipitously to the shoreline. Boulder beaches are common. Large plumes of sediment are visible in the sea. This section of the coast is very different from any of the other coasts of Anatolia. Rainfall is heavy, the mountains are thickly covered by forest, the area is green throughout the year and agriculture is of major importance in this zone.

The deltas of the Kizilirmak and the Yesilirmak Rivers are major deltas protruding into the Black Sea. These are two of the largest rivers in Turkey. The deltas formerly were swampy with many coastal lagoons. They still are very swampy and muddy in their lower reaches in the rainy season. However, here again, large amounts of water have been removed from the streams at the head of the deltas and diverted for irrigation projects. Nevertheless, these two major rivers still supply a massive amount of sediment into the Black Sea. The deltas protrude across the fault boundary of coastal northern Anatolia into the Black Sea. The shelf to -200 meters is fairly wide in this area. Offshore submarine contours show that the deltas were of much greater extent on former times (during the Quaternary Period). Here again, the shelf between Sinop, the Kizilirmak delta, and the Yesilirmak delta is probably comprised of late Neogene and Quaternary Period sediments transported from central Anatolia by these two major rivers. Samsun, a major seaport between the two deltas, lies in an embayment on a small delta plain.

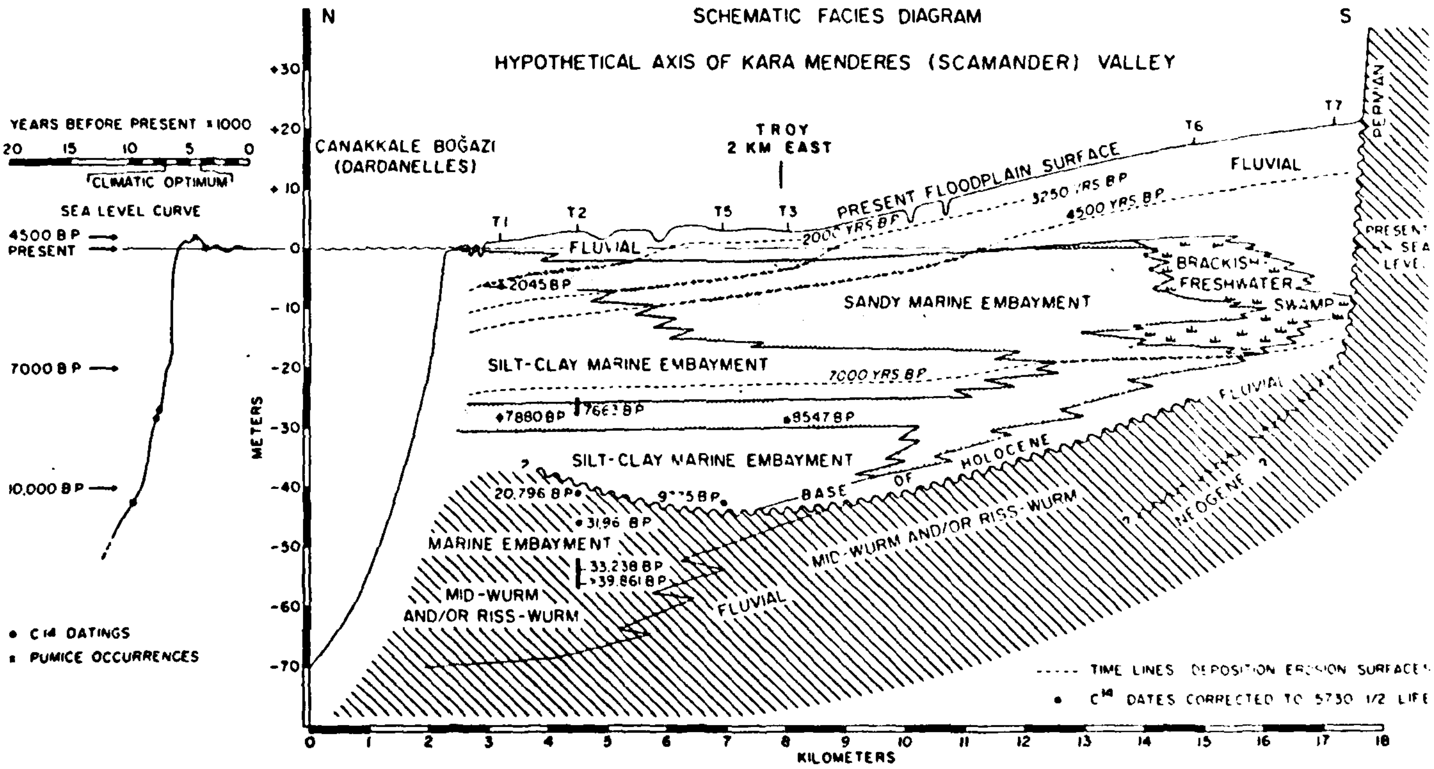

Figure 3. A geologic cross-section and profile of sediments and an associated relative (possibly eustatic) sea level curve for the Anatolian coasts. The cross-section shows a major marine transgression accompanying sea level rise with the waning of the last major ice sheets of the Pleistocene Epoch and the progradation of a delta plain infilling the 15 km marine embayment extant approximately 7,000 years before present. An attempt has been made to provide time depositional lines to show the type of delta progradation and river floodplain aggradation of sedimentary infill of an embayment through the later Holocene Epoch (past 7,000 years). Sediment transport and deposition in the delta, of course, continues.

Observations

Thus, it can be seen that there are three fundamentally different coastal types with different coastal processes, different cliff coast types, and different modern sediment coast types on the Anatolian massif. The Black Sea shoreline is one receiving a large amount of moisture. The two largest rivers in Turkey have their deltas along this coast. Nevertheless, the drop off into the deep basin of the Black Sea is very sharp and the deltas are therefore restricted as the massive sediment flowing from the Kizilirmak and Yesilirmak Rivers have formed a present and Pleistocene (submerged) delta and yet the majority of the sediments that must have come off the Anatolian massif have been transported into the deeper basin of the Black Sea or removed by littoral transport. The shorelines of the Aegean Sea are dominated by grabens which must be presumed to be tectonically active as supported by limited extremely detailed earthquake information (Ilhan, 1971; and other unpublished data). Along the Aegean shoreline numbers of very important ancient cities have been bypassed by delta progradation. This process continues. For instance, the delta of the Buyük Menderes River has reached the outer limits of the mountain ranges flanking the graben and is now protruding into the Aegean Sea. Accordingly, littoral processes become more important in removing sediment from the tip of the delta. On the other hand, as noted before, the modern large port of Izmir is located on an embayment in which a river is depositing a flanking prograding delta. However, engineering works and the removal of water by irrigation has slowed down this process of degradation of the embayment to Izmir (in the sense of it being a major port). The southwest corner of Turkey along the Aegean shore is unique in that it is a classical drowned shoreline. Mountainous ridges drop sharply to the sea and thence under the sea in deep embayments. There is a small amount of sediment in the littoral transport stream but no deltas occur. The stability of this area is somewhat in question as there are some evidences of submergence of sites.

The Mediterranean shoreline varies from a large mountain range trending northsouth on the western end of the Anatolian massif with sharp cliff-like coasts, to a broad travertine step-like series of plateaus rising high above the sea, to coast parallel mountain ranges dropping sharply to the sea, to the major multiple delta region of the Çukurova plain in the southeastern corner of Turkey or northeastern corner of the Mediterranean Sea. This is immediately contrasted to the Gulf of Iskenderun which lies between the Anatolian massif and mountain ranges trending southward through the Turkish province of Hatay and into Syria. The Gulf of Iskenderun accordingly appears to be a down thrown graben but as it is not fed by major rivers, no delta has developed at its head. Accordingly it has become an important port site.

Tectonic activity along the shorelines of Anatolia are in some cases extremely active and appear to have had a short term (past 100 years or less) effect on coastal configurations. For instance, based on some archaeological excavations in the Biga Peninsula, there appears to be a possibility of one-two meters of uplift over the past several thousand years. It must be assumed that the grabens of the Aegean are subsiding in a manner that will effect shoreline configuration and sediment distribution patterns (possibly over the short term event). The southern coast of Anatolia is considered by Erol (1976) to be stable over the past several thousand years. Indeed a wave cut notch of up to one meter can be observed along much of the shoreline along the south central and southeastern part of the Mediterranean shore. This notch may be a feature formed by very slight (less than 1 meter) fluctuations in sea level over the past several thousand years. On the other hand, when one examines the ancient port of Antioch (Antakya) in the extreme southeast in Hatay, the harbor facility of 2,000 years ago is uplifted several meters above the present sea level. This suggests tectonic uplift. However, it may be argued that this is a matter of a fluctuation of eustatic or world sea level up and down within that time. The ancient port of Selucia ad Orontes is literally "up in the air". Further, a modern wave cut notch that is similar to the wave cut notches seen along the southern shoreline of the Anatolian massif may be observed to be well developed in this region.

Turkish scholars feel that sea level rose to its present position about 6,000 years ago and has fluctuated up and down since that time (Erol, 1978 ; Figure 3). Evidences for this eustatic or absolute sea level fluctuation curve comes from many types of sea level fluctuation indicators and from a wide area around the coast of Anatolia. Should this curve of variation of sea levels be correct, then it may suggest and/or reflect highly variable climatic changes worldwide and locally in the Anatolian area. Regardless, such variants of sea levels would lead to increases and decreases in erosion, deposition, and ultimate form of the depositional shorelines of Anatolia. A detailed study was made in the area of the Kara Menderes River in Anatolia as part of this project and also part of another research project carried on by myself and my colleagues. Cross-section Figure 3 is an example of what might be learned by studying the longer term geological sedimentary depositional record (past 10,000 years) of many of the other type of Anatolian deltas. A coastal embayment in the Kara Menderes valley at the mouth of the Dardanelles extended 15 km south of its present shoreline position. Since 7,000 years before present, this entire embayment has been infilled with an excess of sediment flowing into the Dardanelles and retransported by littoral transport, some around the cape and southward along the Aegean shoreline. Shoreline changes of

this magnitude are common elsewhere along the Anatolian shoreline. More important, however, is that evidences shown in Figure 3 suggest that there has been, in fact, strong fluctuations in the amount of sediment flowing to the sea and thus into the littoral transport system over the past several thousand years. Indeed, as indicated in Figure 3, four major surges of sediment have been indicated. These may be a result of climatic fluctuation in the hinterland or a result of some other unknown processes.

Many of the cliff-type coasts of Turkey are comprised of ancient indurated sedimentary, igneous, and metamorphic rocks. These shorelines are not undergoing rapid change in the shorter time frame. However, coastal erosion is occurring at a slow rate and sediment is moving in the littoral transport system. Much of this sediment is being provided by the deltas that intrude into the sea from the mountainous valleys. Except in the area of deltas, there is a very rapid and sharp drop off into deeper waters along most of the cliff-type coasts of Turkey. On the other hand, areas of Turkey that have cliff-type shorelines comprised of soft Tertiary Period sediments are actively undergoing erosion in the shorter time frame. Evidences are abundant indicating the disappearance of all or part of ancient cities. For instance, on the Biga Peninsula near the mouth of the Dardanelles, the ancient city of Sigeum has disappeared by coastal erosion and cliff retreat. The soft Neogene (Tertiary) is undergoing constant erosion, even under moderate wave conditions. In times of extreme storm wave conditions, erosion is accelerated. Precise rates of coastal erosion cannot be obtained because the map evidence for the region over the past several hundred years is not very precise. On the other hand, there are cases of villages that have been forced to be moved during the past 30 years because of the rapidity of coastal retreat or wave cut cliff retreat. One of these sites was noted near the Dardanelles where ancient Sigeum has disappeared.

Conclusions

The implications of these studies to date, in terms of locating new ports or engineering structures in old port sites are obvious. In some cases present day coastal processes are so active as to require intense study before actions might be taken. In other cases, the coasts of Anatolia are stable in terms of erosion and anticipated tectonic events. Studies of past history of earthquake activity and of the major active fault systems of Turkey can also be used to predict and determine types of structures and optimal locations for port sites along the Shorelines of Anatolia.

Work is continuing on the construction of a series of examples of detailed geological-geomorphological-process models of varied coastal types of the shorelines of Anatolia. By use of our geological reconnaissance, presently existing geological and topographic maps, and Landsat photographs, we are attempting to correlate processes of change over both the shorter (tens and hundreds of years) and longer geologic time. These models will be presented as examples integrated with a topographic-structural-tectonic map of Anatolia as indicated in Figure 4.

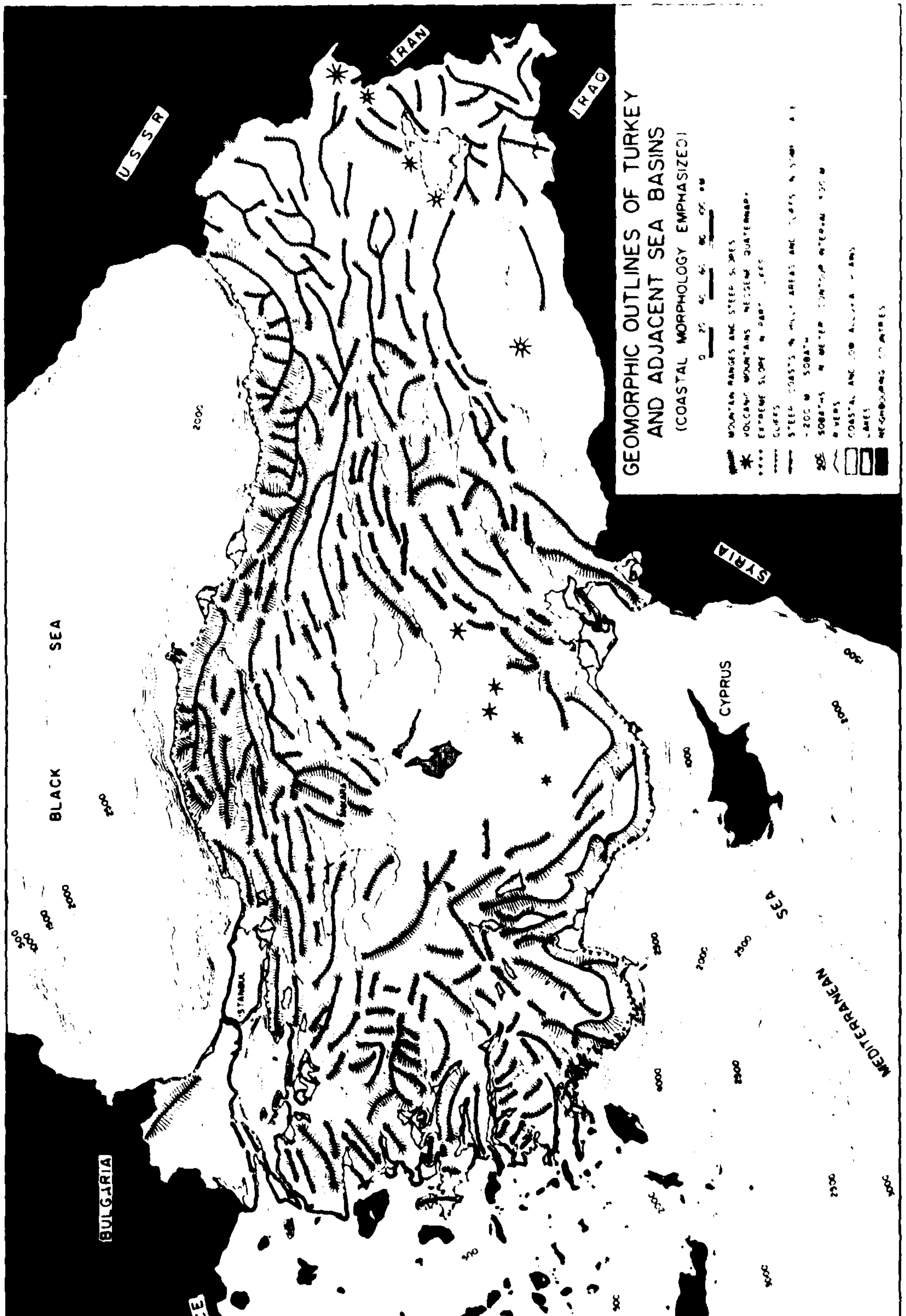

Figure 4. A preliminary schematic, topographic, structural-tectonic map of Anatolia.

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dation. A similar situation
River just to the north of the Buyuk Menderes valley. Th
Menderes River is famous for being the river which formed
which bypassed the important ancient city and capital of
province of Asia, Ephesus (Efes). Linear mountain ranges
east-west protrude into the Aegean Sea. The embayments b
them are being infilled by sediment.

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